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TWO X-RAY PULSARS: 2S1145-619 AND 1E1145.1-6141

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ABSTRACT

Observations from the Einstein Observatory reveal a previously unreported source, 1E1145.1-6141, within 15 arcmin of 2S1145-619 and of comparable intensity during July 1979. Periodicity analysis of the data shows a 290±2s period for the 2S source and a 298±4s period for the 1E source, confirming the previous Ariel V report of two periods in this range from this region of the sky.

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I. INTRODUCTION

The Einstein Observatory (Giacconi et al. 1979) has been used to search for X-ray emission from the vicinity of several of the unidentified COS-B γ-ray sources (Mayer-Hasselwander et al. 1979). In July 1979, data were obtained with the imaging proportional counter from the vicinity of the γ-ray source CG295+0. The 1° square field of view clearly showed two point-like images, separated by 15 arcmin, each of which is located to an accuracy of about 1 arcmin. One source is 2S1145-619 (Dower et al. 1978, Bradt, Doxsey, and Jernigan 1979), the other is a previously unreported source we designate 1E1145.1-6141. Periodicity analysis shows a 290±2 s period for the 2S source and a 298±4 s period for the 1E source. This discovery provides a simple explanation for the previous Ariel V report (White et al. 1978) of two periodicities from this region of the sky since both sources would be within the Ariel V field of view. Our period values are consistent with the more precisely determined Ariel V values (1977 epoch) of 291.8 and 297.4 s.

Approximately 15 other X-ray pulsars have been detected out of the more than 500 known X-ray sources. Such sources are believed to be magnetized neutron stars orbiting relatively ordinary stars, and the orbital parameters of six X-ray binary pulsars have been determined sufficiently to establish neutron star masses as well as other astrophysical information. Future observations of these two additional pulsars may also yield similar data.

II. OBSERVATION AND RESULTS

The X-ray picture of the region is shown in figure 1. The two sources under discussion are located near the eastern (right) side of the image with

the 1E source north of (above) the 2S source. In addition to these point-like sources there is some diffuse emission consisting of a bright "knot" and arc-shaped emission surrounding the knot extending southward to the edge of the field. A detailed examination of the knot and arc will be the focus of future Einstein observations.

The observation was obtained during 1840 seconds of 13 July 1979. With the exception of two gaps of 100 and 150 seconds, the data stream was continuous. Harmonic analyses of the data from each point source showed that each was periodically variable with periods in the range seen by Ariel V. The best values of the periods and the significance levels of the detections are taken from folding analyses in which the arrival times of the photons were folded into phase bins, the bins were corrected for slight nonuniformities in exposure, and χ^2 values calculated for each trial period over the range of periods 200 to 400 s. Harmonic analysis showed that 2S1145-619 had significant power at the first overtone frequency as well as the fundamental, indicating a pulse profile sharper than sinusoidal. Therefore the data were folded into 10 phase bins for 2S1145-619. For 1E1145.1-6141 there was no evidence for a non-sinusoidal profile and 4 phase bins were used. Although the knot source appears to be extended and therefore an improbable candidate for pulsation, for the sake of completeness the arrival times of the photons from its center were also folded with periods spanning the range 200 to 400 s. No significant periodicity for this source was seen.

Figure 2 shows the values of χ^2 per degree of freedom for both point sources as a function of trial period. For 2S1145-619 the best period, 290±2 s, has an associated χ^2 per degree of freedom of 7.4. The probability that random fluctuations alone are responsible for this peak is less than 10^{-10}, there-

fore the detection of periodicity in the intensity 2S1145-619 is virtually certain. The best period value for 1E1145.1-6141 is 298±4 s with a confidence level of < 5×10^{-5}. Although this detection is not as strong statistically as the 2S result, the evidence is highly suggestive, in view of the correspondence of the period we obtain with the larger Ariel V period, that the 1E source is pulsed and is responsible for the second periodic signal from this region of the sky.

Figure 3 shows the pulse profiles of each of the sources. The dominant feature of the profile for 2S1145-619 is a relatively narrow peak in intensity of approximately 4 times the steady value, whereas 1E1145.1-6141 exhibits a much smoother variation. If we take the steady component of 2S1145-619 from the six lowest phase bins we find a pulsed fraction, corrected for background, of 34±5% and a duty cycle of 40%. The pulsed fraction for 1E1145.1-6141 is 51±11% with a duty cycle of ~75%. These large duty cycles are typical of the values seen in other X-ray pulsars (e.g. Rappaport and Joss 1977).

The energy spectra of these sources have been estimated under the simplifying assumption that gain variations over the face of the imaging proportional chamber may be ignored. Such variations are known to be present and therefore our quoted flux values should be regarded as preliminary until these gain variations are accounted for by the Einstein analysis program under development. The energy flux over the band 0.5 to 3.0 keV for 2S1145-619 is approximately 1.3×10^{-11} erg/cm^2-s, for 1E1145.1-6141, 0.9×10^{-11} ergs/cm^2-s. The energy spectrum of the 2S source appears to be cut-off sharply both below 0.5 keV and above 2.5 keV. The spectrum of 1E1145.106141 is dissimilar in that it has a low energy cut-off near 1 keV and there is no evidence for a higher energy cut-off. We have fitted the data to several simple spectral

models and derived estimates of the hydrogen column density which may be responsible for the apparent absorption. These estimates are: $5\pm3 \times 10^{21}$ H atoms/cm^2 for the 2S source and $3\pm2 \times 10^{22}$ H atoms/cm^2 for the 1E source. If the 2S source is identified with the 9th magnitude B emission line star HEN 715 (White et al.1979, Dower et al.1978) at an estimated distance of 1.5 kpc, and if the line of sight column density is a reliable indicator of distance, then 1E1145.1-6141 is at a distance of ~9 kpc, implying a luminosity in the band 0.5 to 3 keV of $\sim10^{35}$ erg/s. Source self-absorption, which is likely to be present for both sources, may distort the distance and luminosity estimates considerably.

The best position of 1E1145.1-6141 is: $\alpha = 176\overset{\circ}{.}29$, $\delta = -61\overset{\circ}{.}68$, with an estimated error radius of 1 arcmin. We have examined an ESO survey plate of the region around 1E1145.1-6141. The error circle is located in a relatively crowded region of the galactic plane containing perhaps seven stars brighter than 17th magnitude with the brightest estimated to be fainter than 13th magnitude. Our best position of 2S1145-619 is: $\alpha = 176\overset{\circ}{.}417$, $\delta = -61\overset{\circ}{.}925$, 0.8 arcmin from the position of the optical counterpart, HEN 715 and consistent with it.

III. DISCUSSION

There is no evidence for non-periodic variability of either source over the half hour interval of our observation. However the combined flux of both sources is nearly 10^2 smaller than the maximum 2-6 keV flux quoted for 4U1145-61 (Forman et al. 1978). The quoted 4U position and error box agrees with neither the 2S nor the 1E source position and therefore both may have contributed significantly to the Uhuru flux values. Therefore one

or the other or both sources are apparently variable by a large amount over long periods of time. From the variation of the amplitudes of the periodic signals seen by Ariel V (White et al. 1978) variability of a factor of 7 on a time scale of months may be attributed to 2S1145-619 and variability by a factor of 2 on a time scale of days may be attributed to 1E1145.1-6141.

The reader may wonder about the apparent improbability of finding two X-ray pulsars so close together on the celestial sphere. In order to assess this probability realistically the observed non-uniformity of the distribution of X-ray pulsars must be considered. For example, of the 15 known galactic X-ray pulsars four (two of which are discussed in this paper) lie between galactic longitudes 292° and 296° and within 1° of the plane. This clustering appears to be an illustration of an enhancement in a distribution of population I objects near a tangent line to an inner spiral arm. In this case the arm is the so-called Sagittarius-Carina arm (e.g. Georgelin and Georgelin 1976), one of the major arms of the galaxy. Because of this non-uniform distribution the chance coincidence of two X-ray pulsars within 15 arcmin of each other is not negligible.

The association of either X-ray pulsar with the γ-ray source, CG295+0, is without foundation at this time in view of the lack of any previous relationship between X-ray pulsars and the unidentified γ-ray sources. However, a search of the COS-B γ-ray data for periodic signals in the range we have observed should be pursued. Future observations of these X-ray pulsars over extended periods of time should yield the rate of change of the periods with time, possible correlations between intensity and spectral changes, and may yield orbital determinations from which the neutron star masses can be derived.

We gratefully acknowledge the efforts of many people of the Harvard-Smithsonian Center for Astrophysics who have contributed to the success of the Einstein Observatory and the guest investigator program. We particularly acknowledge the help of F. Seward, W. Forman, R. Harnden, and C. Jones. We also thank N. White of NASA Goddard Space Flight Center for his communication with us regarding additional evidence for the two periods (N. White et al. 1980). This work was supported in part by the U. S. National Aeronautics and Space Administration under contract NAS8-33334.

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Figure 1. X-ray picture obtained with the imaging proportional chamber. The field of view of $1° \times 1°$. The two X-ray pulsars under discussion are located near the eastern (right) side of the image with the 1E source north of (above) the 2S source.

Figure 2. Results of the folding analyses for 2S1145-619 (upper graph) and 1E1145.1-6141 (lower graph). χ^2 per degree of freedom is plotted as a function of the folding period. The best value of the period for each is indicated in the figure. The confidence level that random processes are responsible for the 2S result is $<10^{-10}$, for the 1E result $< 5 \times 10^{-5}$.

Figure 3. Phase plots for 2S1145-619 (upper graph) and 1E1145.1-6141 (lower graph). The non-source background as a percentage of the total counts in the phase plot is 4% for 2S1145-619 and 11% for 1E1145.1-6141.

EINSTEIN OBSERVATORY
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RA,DEC: 177.313 -61.[illegible]7
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26-SEP-79

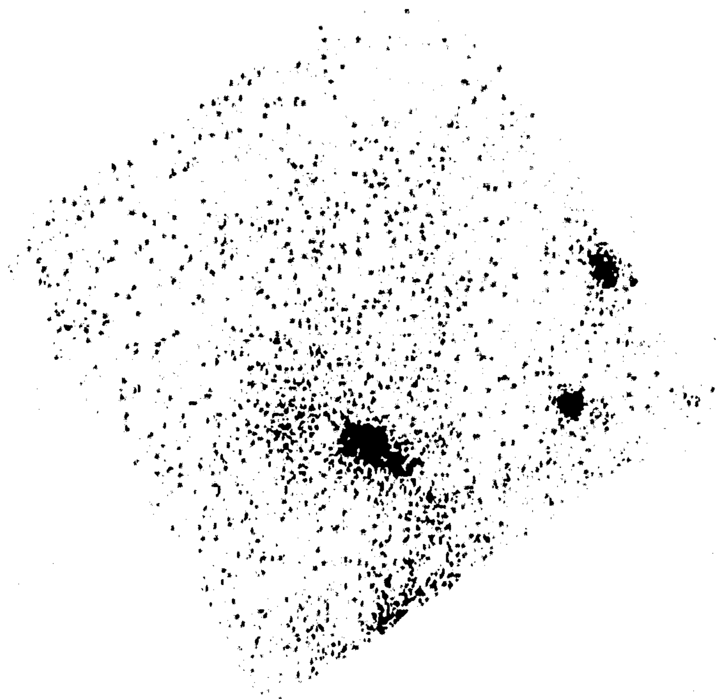
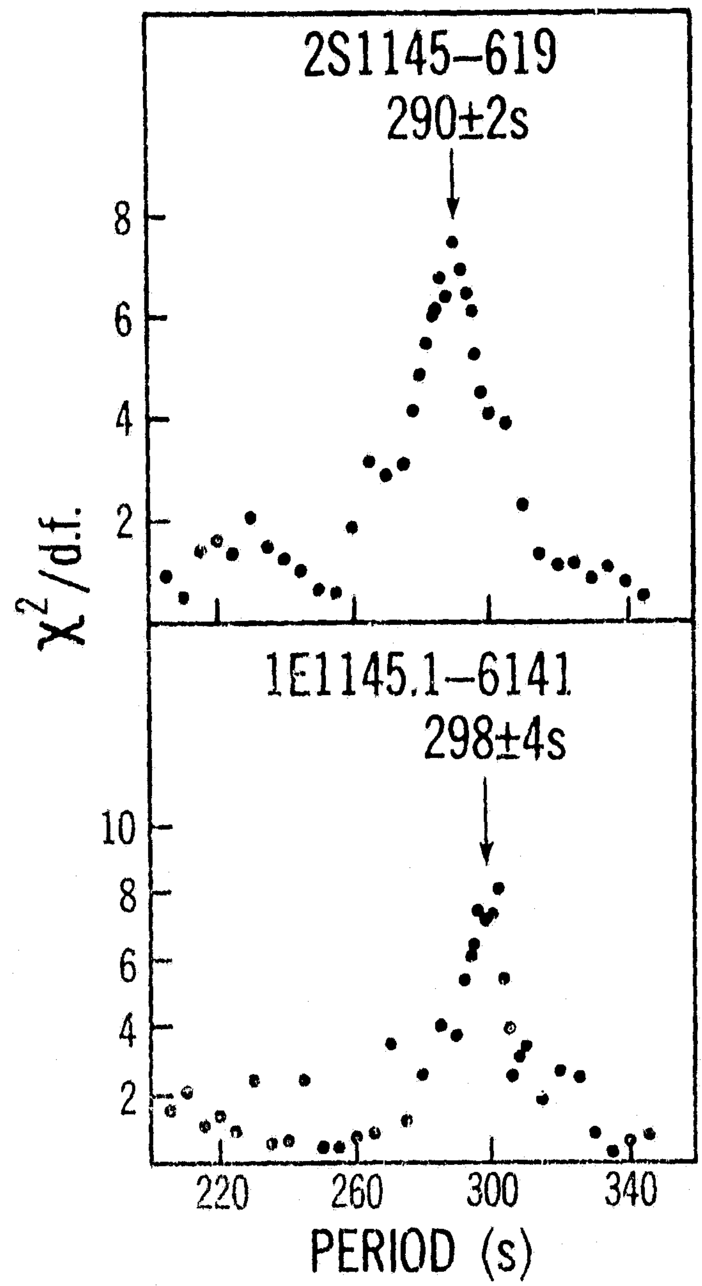
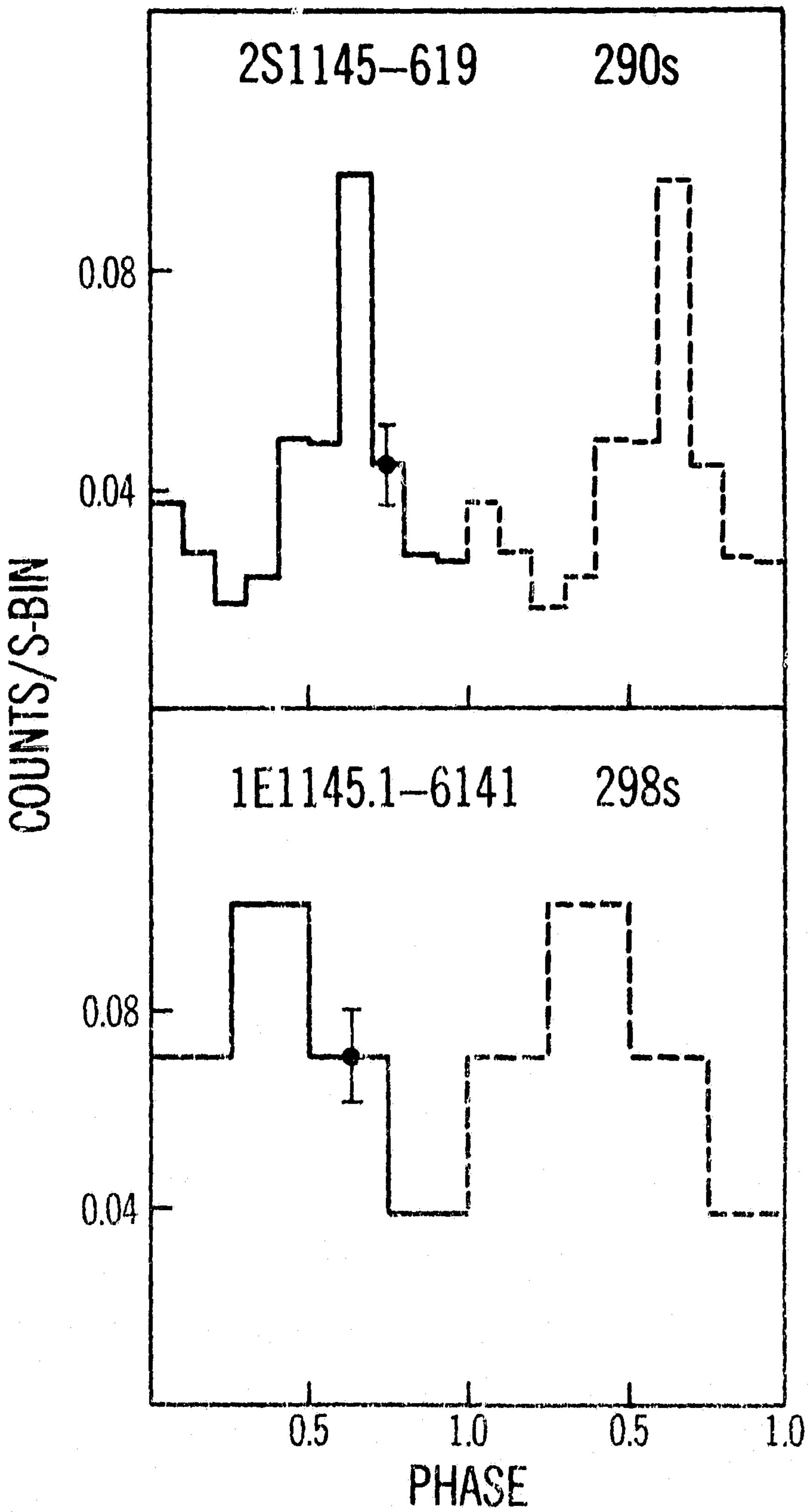


Figure 1



2S1145−619
290±2s
8
6
4
2
χ^2/d.f.
1E1145.1−6141
298±4s
10
8
6
4
2
220
260
300
340
PERIOD (s)

Figure 2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290s
1E1145.1–6141
298s
0.08
0.04
0.08
0.04
COUNTS/S-BIN
0.5
1.0
0.5
1.0
PHASE

Figure 3

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